Seafloor Geomorphology, Gas & Fluid, and Slope Failure on the Southern Cascadia Continental Margin

Daniel L. Orange
Department of Earth Sciences - University of California
Santa Cruz, CA 95064
phone: (831) 459-4089 fax: (831) 459-3074 email: dano@es.ucsc.edu
Award# N00014-98-1-0503

LONG TERM GOAL

Our long term goal is to understand the role of fluid flow and gas migration in the creation and modification of shelf and slope geomorphology. In addition, we are examining the interaction of tectonics, sedimentation and erosion in creating and modifying the morphology, stratal architecture and preservation potential of continental margins.

OBJECTIVES

We are examining how hydrogeology, natural gas, and tectonics interact and influence submarine geomorphology by combining seafloor data and subsurface imaging. Our goal is to determine the causes of anomalous seafloor bathymetry and reflectivity, and to relate reflectivity to gas migration, subsurface structure, and consolidation state.

APPROACH

Our primary data sets are the EM-1000 multibeam data (both bathymetry and backscatter) and a nested suite of subsurface geophysical data. We use commercial multichannel seismic (MCS) reflection data provided by Amoco Corp. to interpret the deep (>1 km) subsurface geology in the Eel River Basin. By combining our analyses of these data with STRATAFORM high resolution MCS data (Craig Fulthorpe, UTIG and Greg Mountain, LDEO) and even higher resolution Huntec (Mike Field, USGS) and EdgeTech CHIRP (Neal Driscoll, WHOI), we can examine structural and sedimentologic features at scales from several meters to kilometers sub-surface. These nested subsurface techniques are then be combined with seafloor bathymetry and reflectivity data to determine the relationship between structure, gas, bathymetry and reflectivity. To groundtruth our hypotheses we participated in a Monterey Bay Aquarium Research Institute (MBARI) sponsored ROV program to the Eel River Basin in August, 1997. We are integrating our observations with the seafloor and subsurface data to analyze active vs. dormant processes, and constrain the role of fluid and/or gas migration in creating or modifying seafloor structures.

We are also carrying out a theoretical study exploring the lack of slope failure in the Eel River basin. Specifically, we are examining the relationship between seismicity and slope failure by evaluating the attenuation of seismic waves in shallow sediments. We are carrying out this work in collaboration with Lincoln Pratson (Duke).

Report Documentation Page					*Form Approved* *OMB No. 0704-0188*
Public reporting burden for the collection of information is estimated to average 1 hour per response, including the time for reviewing instructions, searching existing data sources, gathering and maintaining the data needed, and completing and reviewing the collection of information. Send comments regarding this burden estimate or any other aspect of this collection of information, including suggestions for reducing this burden, to Washington Headquarters Services, Directorate for Information Operations and Reports, 1215 Jefferson Davis Highway, Suite 1204, Arlington VA 22202-4302. Respondents should be aware that notwithstanding any other provision of law, no person shall be subject to a penalty for failing to comply with a collection of information if it does not display a currently valid OMB control number.					
1. REPORT DATE **1998**		2. REPORT TYPE			3. DATES COVERED **00-00-1998 to 00-00-1998**
4. TITLE AND SUBTITLE **Seafloor Geomorphology, Gas & Fluid, and Slope Failure on the Southern Cascadia Continental Margin**					5a. CONTRACT NUMBER 5b. GRANT NUMBER 5c. PROGRAM ELEMENT NUMBER
6. AUTHOR(S)					5d. PROJECT NUMBER 5e. TASK NUMBER 5f. WORK UNIT NUMBER
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) **University of California,Department of Earth Sciences,Santa Cruz,CA,95064**					8. PERFORMING ORGANIZATION REPORT NUMBER
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)					10. SPONSOR/MONITOR'S ACRONYM(S) 11. SPONSOR/MONITOR'S REPORT NUMBER(S)
12. DISTRIBUTION/AVAILABILITY STATEMENT **Approved for public release; distribution unlimited**					
13. SUPPLEMENTARY NOTES **See also ADM002252.**					
14. ABSTRACT					
15. SUBJECT TERMS					
16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
a. REPORT **unclassified**	b. ABSTRACT **unclassified**	c. THIS PAGE **unclassified**	**Same as Report (SAR)**	**7**	

Standard Form 298 (Rev. 8-98)
Prescribed by ANSI Std Z39-18

WORK COMPLETED

* We have completed our analysis of observations made during the MBARI-funded ROV program. These observations have been integrated with the seafloor and subsurface data, resulting in a process-oriented interpretation of fluid and gas migration in the Eel River basin.

* We participated in a July, 1998 STRATAFORM cruise to the northern California study area to investigate the anomalous reflectivity on the subaqueous deltas. We are collaborating with Neal Driscoll (WHOI) on the interpretation of these data.

* We have loaded industry geophysical data onto a Landmark workstation, and combined these with paper copies of additional industry data. We have a preliminary regional interpretation of the subsurface structural geology.

* We have completed a computer model that examines the attenuation of seismic waves through saturated porous media. Initial results suggest a variety of mechanisms that result in a stable slope and the observed lack of slope failure.

RESULTS

Integrating ROV Observations with Geophysical Data:
The primary goal of the MBARI-sponsored 11-dive ROV program was to identify and sample sites of active fluid venting. ROV dives were conducted along the floor of the Humboldt Slide, on the offshore projections of the Little Salmon fault and Table Bluff anticline (on both the shelf and slope), within the gullied region of the slope north of the Little Salmon fault, and within the Eel Canyon. All of the active seep communities and authigenic carbonate occurred above structural features. We observed no evidence for active fluid flow, and no authigenic carbonate, within pock marks north of the Little Salmon fault, on the base of the Humboldt Slide, or on the sedimented shelf and slope. These observations contradict the geophysical data, where much of the evidence for gas (wipe outs, bright spots, pock marks) occurs in shore-parallel zones, oblique to the local structural trends (for more discussion, see Orange, FY97 ONR 32 Final Report). This suggests two different mechanisms for fluid expulsion: continuous along structure vs. episodic (and catastrophic) between structures.

Modeling Seismicity and (the Lack of) Slope Failure:
We have completed a computer model that analyzes the attenuation of seismic energy with propagation through a layered porous media of variable physical properties. Our modeling shows that if the subsurface sediments are characterized by low velocities (due to underconsolidation or overpressures), then a significant amount of energy may be either reflected or refracted away from the surface; inelastic energy losses may also suppress strong shaking at the surface. This mechanism may help explain the paradoxical lack of slope failures on the seismically active Eel River margin.

The Ridge and Swale Zone:
High resolution multibeam and seismic reflection data show a series of alternating seafloor highs and lows on the upper slope (water depths 150 - 300 m). These features, known informally as the “ridge and swale” zone, are oblique to the continental slope, have amplitudes of 5-10 m, wavelengths of ~500 m, and lengths of up to 8 km. The seaward (west-facing) slopes of the ridges have higher acoustic

backscatter than the intervening swales. The southern boundary of the ridge and swale zone is associated with the Little Salmon fault.

High resolution seismic profiles demonstrate that the surface geometry of the ridge and swale zone mimics the underlying stratal morphology (Figure 1). Moreover, the upper sequence onlaps onto an underlying sequence, and systematically backsteps landward; reflectors become more conformable seaward and some terminate by downlap. This stratigraphic architecture is repeated by underlying sequences.

The apparent onlapping stratal geometry and backstepping pattern suggest sequence deposition during periods of relative sea level rise. Both the packets of beds and individual beds are variable in thickness and extent, and these variations might reflect differences in sedimentation during transgression. In this scenario, the pronounced angular unconformities were formed during relative sea level falls. Alternatively, these sequences may represent sedimentation concurrent with punctuated tectonic uplift related to the Little Salmon fault.

Three Structural Styles in the Eel River Basin:
The southern Eel River Basin appears to have at least three distinct modes of structural deformation, each influencing both the long-term stratal architecture and the migration of gas to near-surface sediments. The structural styles include open anticlines, positive flower structures that reach the seafloor (indicative of Recent transpressional strike-slip movement; Figure 2), and broad uplift of the basin margin near the Mad River fault zone. West-northwest trending strike-slip faults are observed only on the continental shelf, and two appear to reach near-surface sediments. In contrast, large open anticlines trend northwest and for the most part do not reach near-surface sediments on the shelf.

We find that the study area north of the offshore strike of the Little Salmon fault is relatively free of pervasive structural deformation, and has been a sedimentary depocenter probably since the formation of the Eel River basin. In this area, a major bounding unconformity (Pleistocene?) can be traced from the inner shelf to the upper slope. Parts of this unconformity are also traceable south of the offshore strike of the Little Salmon fault, but reflector discontinuity due to gas, structural complexity, and data gaps inhibit confident interpretation at this point.

IMPACT/IMPLICATIONS

Our investigation of seafloor morphology and reflectivity suggests that high resolution multibeam may be of use to the hydrocarbon and cable industries as both an exploration tool and a means of conducting cost-effective geohazard surveys. We have demonstrated an approach that identifies anomalous seafloor features and relates them consolidation state and possibly to shallow gas. We have shown that high resolution multibeam data can be used to document seafloor seepages, and such seepages in petroleum environments provide direct samples of the fluids and hydrocarbons in a basin without exploration drilling; subsurface data can facilitate seep interpretation. The same data used for targeting seeps can also used for geohazard analysis. Geohazards that can be identified include oversteepened slopes, regions of pre-existing slope failure, areas of excessive gas (indicated by pock marks and subsurface acoustic blanking), and mud volcanoes. High-resolution multibeam data can provide georeferenced data at a resolution similar to deep towed side scan, but at higher speeds and wider swath widths for greater

efficiency. Multibeam data are most effective when combined with high resolution sub-bottom profiling and multichannel seismic data.

Our ROV surveys, when combined with seismic data, show that gas migration may significantly affect seafloor backscatter intensity. We have shown that structural highs on this gas-rich margin are regions of long term gas expulsion, with consequent bacterial oxidation leading to carbonate precipitation. This carbonate can armor the seafloor and significantly increase backscatter intensity. This phenomenon may be widespread on continental margins, leading to the prediction of increased backscatter on structural highs on any continental margin known to contain subsurface gas.

TRANSITIONS

By documenting tectonically uplifted regions where deep basinal reflectors approach the seafloor, our work will help define deep coring locations where reflectors can be sampled and extrapolated to the basin at large. This will aid in the interpretation of long-term sequence stratigraphic packages.

Work on the tectonic history of the Eel Basin directly impacts STRATAFORM by contributing to the knowledge base about long-term ($> 10^5$ yr) strata preservation.

RELATED PROJECTS

Our work on the interaction of gas,seafloor morphology and reflectivity is now being expanded upon by high resolution sub-bottom profiling (CHIRP sweep-frequency sonars) surveys being conducted by Neal Driscoll (WHOI). We are also working with Larry Mayer (U. New Brunswick) in assessing methods to associate the presence and amount of gas in near-surface sediments with the azimuthal variation of seafloor backscatter.

We are working with Mike Field and Jim Gardner (USGS) in analyzing and interpreting Huntec high-resolution sub-bottom data, focusing on the Ridge and Swale zone. We are collaborating with Craig Fulthorpe (U. Texas) and Greg Mountain (LDEO) in integrating our studies of the commercial MCS data with their high resolution MCS data.

ROV observations and sampling on both the shelf and slope are helping Larry Mayer and John Hughes-Clarke (U. New Brunswick) and John Goff (U. Texas) groundtruth acoustic reflectivity and swath bathymetry data. ROV samples within the Eel Canyon are assisting Clark Alexander (Skidaway Institute of Oceanography) in determining the importance of this system to sediment distribution on the Eel margin.

REFERENCES

D. Orange, 1998, N000014-96-1-0361 Final Technical Report: Seafloor Geomorphology, Gas and Fluid Flow, and Slope Failure on the Southern Cascadia Continental Margin. FY97 ONR 32 Year End Report.

PUBLICATIONS

Suess, E., Bohrmann, G., von Huene, R., Linke, P., Wallmann, K., Lammers, S., Sahlig, H., Winckler, G., Lutz, R.A., and Orange, D. (1998) Fluid venting in the Aleutian subduction zone, *Journal of Geophysical Research*, v. 103, p. 2597-2614.

Brewer, P.G., Orr, F.M. Jr., Friederich, G., Kvenvolden, K.A., Orange, D.L. (1998) Gas hydrate formation in the deep sea: *In situ* experiments with controlled release of methane, natural gas and carbon dioxide, *Energy and Fuels*, v. 12, p. 183-188.

Orange, D.L., (accepted) Tectonics, Sedimentation, and Erosion in Northern California: Submarine Geomorphology and Sediment Preservation Potential as a Result of Three Competing Processes, *Marine Geology*.

Goff, J.A., Orange, D.L., Mayer, L.A., and Hughes-Clarke, J.E., (accepted) Detailed investigation of continental shelf morphology from a high resolution swath sonar survey over the Eel River Basin, northern California. *Marine Geology*.

Yun, J.W., Orange, D.L., and Field, M.E., (accepted) Gas distribution in the Eel River Basin and its link to submarine geomorphology. *Marine Geology*.

Orange, D.L., Greene, H.G., Reed, D., Martin, J.B., McHugh, C.M., Ryan, W.B.F., Maher, N., Stakes, D., and Barry, J. (accepted), Widespread Fluid Expulsion on a Translational Continental Margin: Mud Volcanoes, Fault Zones, Headless Canyons, and Aquifers in Monterey Bay, California, *Geological Society of America Bulletin.*

ABSTRACTS

McAdoo, B.G., Pratson, L., and Orange, D.L. (1997) Comparative landslide morphology, U.S. continental slope, *EOS (Transactions, American Geophysical Union)*, v. 78, p. F687.

Orange, D.L., Yun, J.W., Foland, S., Maher, N., Martin, J.B., and Wheat, G. (1997) Active and episodic fluid flow on the southern Cascadia continental shelf and slope, *EOS (Transactions, American Geophysical Union)*, v. 78, p. F687.

Yun, J.W., Orange, D.L., Foland, S., and DiLeonardo, C. (1997) Structure and geomorphology offshore northern California as related to gas+fluid venting, *EOS (Transactions, American Geophysical Union)*, v. 78, p. F687.

Lorenson, T.D., Orange, D.L., Brewer, P.G., Davisson, M.L., Martin, J.B., Lillis, P.D., and Kvenvolden, K.A. (1998) Comparison of offshore and onshore gas occurrences, Eel River Basin, Northern California, *(Transactions, American Geophysical Union, Ocean Sciences)*, v. 79, n. 1, Supplement, p. OS71.

Orange, D. L., Yun, J., and Maher, N. (1998) Using high resolution multibeam (bathymetry and reflectivity) and ROV surveys to track fluid and gas seeps on the northern California shelf and slope, *5th International Conference on Shallow Gas, Bologna, Italy, p. 82.*

Yun, J.W. (1998) Tectonic controls on the formation, deformation, and erosion of strata in the Eel River basin, California. SEPM-IAS Research Conference on Strata and Sequences on Shelves and Slopes, Sicily, Italy.

to be presented at fall, 1998, AGU:
Orange, D. L., Field, M., Gardner, J., Driscoll, N., and Mayer, L. (1998) High Resolution Seismic Images of Stacked Transgressive Sequences Proximal to an Active Fault on the Northern California Margin, *EOS (Transactions, American Geophysical Union)*.

Yun, J.W., and Foland, S.S. (1998) Varying structural and stratigraphic character offshore northern California. *EOS (Transactions, American Geophysical Union).*

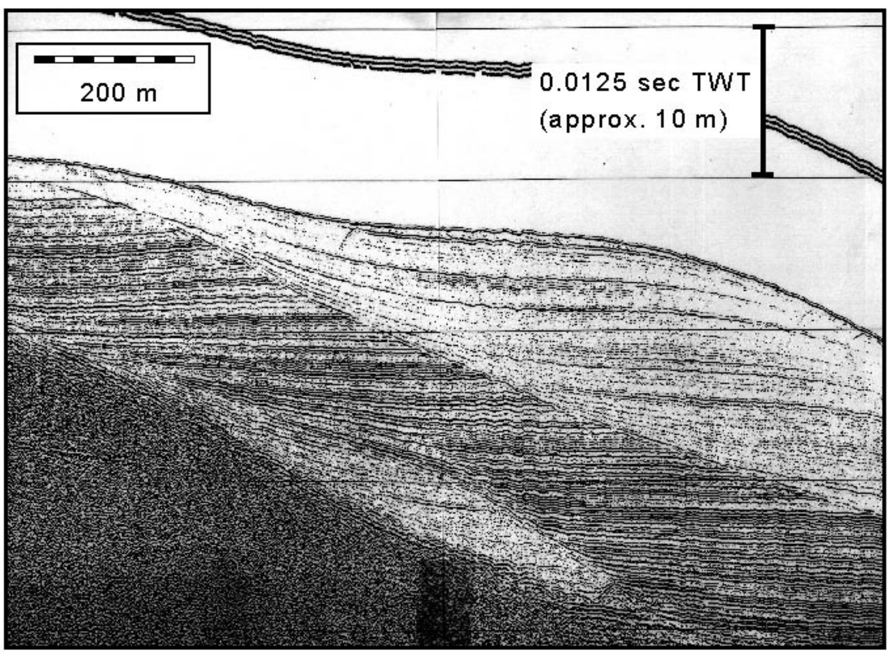

Figure 1: High resolution Huntec seismic image of the Ridge and Swale zone, north of the Little Salmon fault. Image shown is a dip line, looking south. Steeper seafloor (ridges) shows higher backscatter on multibeam data, whereas intervening shallow slopes (swales) are characterized by normal reflectivity. Note the truncation of reflectors in the buried packet, and the basal onlap within the sequences (Huntec data provided by M. Field and J. Gardner, USGS).

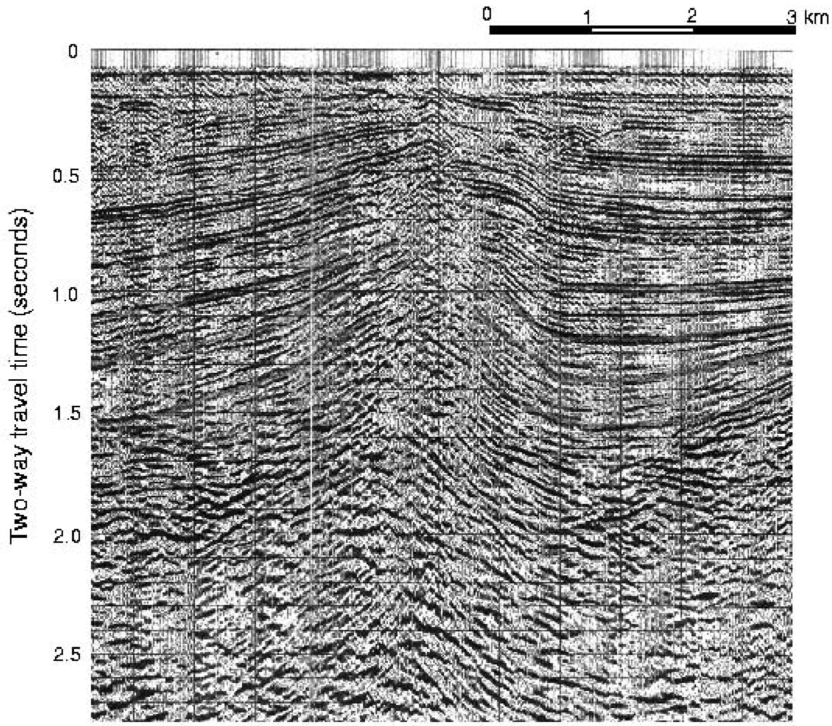

Figure 2. Commercial multichannel reflection profile across the shelf of the Eel margin showing a positive flower structure, indicative of transpressional movement. Near-surface seismic reflectors are deformed by this structure, suggesting recent movement. (Line 108, collected by Jebco Geophysical and is provided by Amoco Corp.)